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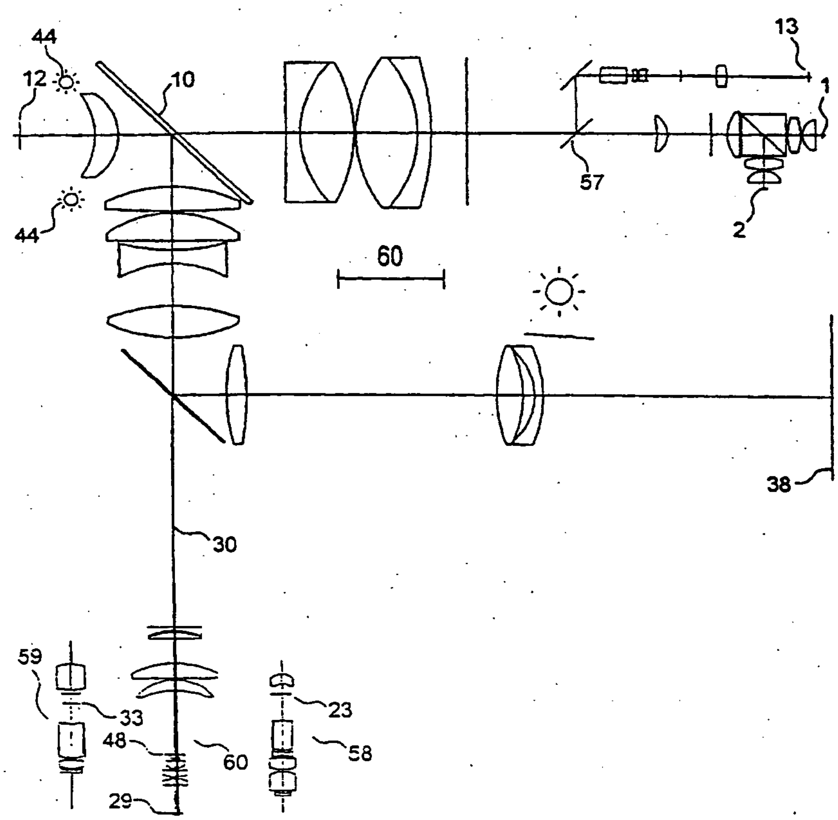
(54) **Title:** OPHTHALMOSCOPE WITH MULTIPLE INTERCHANGEABLE GROUPS OF OPTICAL COMPONENTS



(57) **Abstract:** An ophthalmoscope optical system is described having multiple functions to measure different properties of a patient's eye, using common components and a single camera device. The functions are controlled by moving optical elements and varying the brightness of light sources. The optical path enables full colour imaging, the compensation of toroidal refraction errors in the patient's eye and the measurement of binocular disparities. The optical path contains methods for suppressing ghost reflections from common optical elements and the cornea. The optical system may be linked to a computer to enhance the measurements of the patient's eye.

WO 01/60241 A1

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OPHTHALMOSCOPE WITH MULTIPLE INTERCHANGEABLE GROUPS OF OPTICAL COMPONENTS

This invention relates to an optical system suitable for ophthalmoscopes generally, and more particularly, to an ophthalmoscope that combines multiple functions into one instrument.

The use of digital imaging ophthalmoscopes is now common. They generally illuminate a patient's eye with light, such as from a lamp, laser or light emitting diode (LED). The eye incorporates a lens at the front which is covered by a pupil. The pupil acts as a stop to control the directions and positions of light rays entering the eye. In front of the lens and pupil is the cornea, a strongly curved surface that also acts as a lens. The back of the eye incorporates a light sensitive layer, called the retina, that weakly reflects the light back towards the eye lens. The structure of the retina is encoded on the reflection, and the eye lens in conjunction with the cornea generally collimates the retinal image, projecting it back into the ophthalmoscope. The ophthalmoscope generally splits the reflected light from the illumination light and images it onto a camera system.

Many patient's eyes will exhibit focus errors, of either a rotationally symmetrical form (called spherical error by ophthalmologists) or astigmatic form (called cylindrical error). The optical system in the ophthalmoscope generally compensates for spherical and astigmatic focus errors, by moving a combination of rotationally symmetrical lenses, camera devices and cylindrical lenses within the beam.

Ophthalmoscopes usually view the retina with a CCD camera. Other devices may use film or scanning lasers and detectors.

There is a market for ophthalmoscopes in primary healthcare screening for retinal defects, but they are generally sophisticated and expensive. An advantage in the trade off of cost versus performance would accrue if additional functions could be combined with the digital imaging ophthalmoscope. The costs per function due to manufacturing, marketing and ophthalmologist's practice overheads will be reduced, and patient care enhanced, by combining and matching results from different measurements

The common functions include those in the following list.

Wide field of view retinal imaging.
Full visible plus near infra red imaging.
Narrow field of view imaging with stereo imaging of the optic nerve, where a 3D image of the optic disc is generated to measure glaucoma.
Field screening, where the patient's visual capability is measured over a field of view.
Autorefraction, where the patient's eye is measured for spherical and astigmatic errors of refraction.
Docking, where the ophthalmoscope is aligned to the patient's eye, and additional diagnostic data is available.
Binocular disparity, where the eye's movements in response to stimulation of the other eye is measured.

It is the object of this invention to provide an optical system that can be used to combine three or more of the multiple functions listed above into one ophthalmoscope.

Combining all these functions requires an innovative optical design which is the subject of this disclosure. It is implied that the optical design is part of an overall electro-optical system that includes a host computer, i.e. typically a PC. Electronic hardware is added to the PC, including image capture hardware and motor control servo control boards. The PC is programmed with control and image processing software.

The technical description is of sufficient detail to build an optical system that can be interfaced with a host computer, the host computer only being described in general terms where relevant to the optical specification.

This specific optical design provides the requisite optical path to incorporate the following electro-optical components:

For wide field of view retinal imaging, light from 3 separate colour sources, and one near infra red source, must be projected into the eye, and the light reflected from the retina imaged onto a Charge Coupled

Device (CCD) camera chip. The image sensed by the CCD chip is processed by electronic devices, a computer and software which are outside the scope of this disclosure.

The same electro optic components are used for narrow field of view imaging, except that the optical design must change the magnification of the light pattern relative to the CCD chip dimensions. The addition of stereo imaging of the optic disc requires stereo shutters in the optical path between the retina and the camera, usually by means of polarising liquid crystal cells. The timing of the opening and closing of the shutters is synchronised to the frame periods of the CCD chip. The image processing hardware captures stereo pair images of the optic disc for 3D profiling in computer software. It is not essential to the present invention to utilise an electro optic shutter, other methods being viable.

For field screening, an image from a Liquid Crystal Display (LCD) is projected into the patient's eyes to stimulate the patient to respond. The optical design enables the movement of the patient's eyes in response to be detected, and processed in the computer to classify patient's response versus the stimuli.

For autorefraction, the patient's eye is illuminated with a near infra red source which is projected through a reticule. The light pattern on the retina is modulated by the reticule and viewed by a camera. The optical design enables the reticule and camera to be adjusted in position to focus the light pattern on the retina, and the optical component movements automatically analysed by the computer to measure the patient's state of accommodation.

For docking, the camera is used to view the patient's pupil rather than the retina and the ophthalmoscopes aligned to the eye by adjusting the position of the image of the eye to be central to the axis of the ophthalmoscope, as is predefined on manufacture.

For measuring binocular disparity, a light is shone into one of the patient's eyes to stimulate movements in the other; those movements being imaged through the docking optics.

According to the present invention there are a set of matched optical systems that can be used to combine three or more of the functions listed in Table 1 above into one instrument.

According to the present invention, the design of the optical systems, including the geometry of light sources and stops, is arranged to avoid troublesome ghost reflections. The light projected into the eye may also be linearly polarised, such that specular reflections are blocked by a corresponding crossed linear polariser in the optics between the retina and a camera.

According to the present invention, the retina is illuminated from an assembly of high brightness LEDs containing red, green, blue and near infra red colours. The range of angles over which they illuminate the eye's pupil is greater than the field of view of the imaging optics in the ophthalmoscope. The LEDs are focused onto the pupil of the patient's eye by an optical system, which contains a moving mirror that interrupts the beam to project a reticule image through the same optics onto the retina, for auto refraction measurements. The autorefraction optics have a focus movement of optical components that changes the focus of the projected image over a wide range to accommodate and measure variability in the patient's eyes.

According to the present invention, the illumination optics contain a beamsplitter near the eye. The light reflected from the retina contains an image of the retina, and is reflected from the beamsplitter into imaging optics. The optical path also contains moving cylindrical lenses to adjust for astigmatism in the patient's eye. A moving assembly contains several different lens sub-assemblies that image the retina onto a camera over a narrow field of view and a wide field of view, and also image the pupil of the eye onto a camera. The narrow field of view imaging optics contain an electro optic shutter that switches between left and right pupils to generate stereo pair images of the retina.

According to the present invention, in the imaging optical path, and between the aforesaid beamsplitter near the eye and the stereo shutter, a beamsplitter reflects an image from a liquid crystal display (LCD) into the optical path and back towards the eye, so that the patient

can see images generated on the LCD, that cue various actions by the patient.

According to the present invention, all of the above optics illuminate or view the retina through a single aperture. Two separate illumination optics, comprising a simple approximately collimating lens and visible light source, e.g. LEDs, are added either side of the main aperture to illuminate the untested eye with a visual stimulus. By viewing the movements of the tested eye whilst the other eye is being stimulated, binocular disparities can be measured.

According to the present invention, all of the adjustments and measurements can be undertaken with the near infra red light to avoid false stimulation of the patients' eyes' functions, that would otherwise affect the measurements.

In the following specific description, all dimensions are given in millimetres and all angles in degrees, unless otherwise stated or inferred. A preferred embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a scale raytrace through the illumination optics showing dual LED sources for the near infra red and red, green and blue wavelengths;

Figure 2 is a scale raytrace through the autorefraction illumination optics including a moving reticule and near infra red LED source;

Figure 3 is a scale raytrace through the wide field of view imaging optics, shown folded by the beamsplitter in the vertical direction;

Figure 4 is a scale raytrace through the narrow field of view and stereo imaging optics;

Figure 5 is a scale raytrace through the field screening display optics;

Figure 6 is a scale raytrace through the docking optics, used to align the ophthalmoscope to the patient's eye;

Figure 7 is a scale raytrace through the combined optical functions of field screening display and docking;

Figure 8 is a scale raytrace through the combined optical functions of illumination, autorefraction and wide field of view imaging functions;

Figure 9 is a scale raytrace through the combined optical functions of illumination, autorefraction, narrow field of view and stereo imaging optical functions; and

Figure 10 is a scale diagram of the complete optical system.

An embodiment of the preferred invention will now be described, which combines all of the optical functions necessary to provide the ophthalmology functions listed in Table 1 above.

Alternative embodiments of the invention can be obtained by leaving out components necessary solely for any of the individual functions listed in Table 1. For example, the field screening function can be removed by deleting the field screening display optical components from the system, to generate an alternative embodiment with reduced functionality.

The preferred embodiment will be housed in a structure that is mechanically adjusted relative to the patient's eyes, to align the optical system. The optical system illuminates the patient's eye through an exit pupil that is designed to fit inside the aperture of the patient's pupil. Light projected through this exit pupil will be projected by the structure of the patient's eye onto the retina, where it will be scattered off the retina and be imaged out through the eye's pupil. The structure of the eye causes the reflected image to be projected through the same exit pupil at a conjugate that is close to collimated, though significant variations in focus distance can accrue if the patient's eyes are defective or badly focused. For this reason, all the retinal imaging optical paths will be adjustable to focus out patient's eye variations, by moving components in the optical system, including moving cylindrical lenses to compensate astigmatism.

The preferred embodiment is now described with reference to figures 1 to 10, initially by describing each individual optical function, and then by the combination of functions together.

Figure 1 shows a near infra red LED 1, and a tri-colour LED package 2 containing red, green and blue chips in close proximity. They illuminate two pairs of lenses 4, which may or may not be the same. A dichroic cube beamsplitter 3 combines the light from the four LEDs into one optical path, the dichroic coating serving to maximise the light throughput to the eye. The effect of all the lenses 4, 5, 7, 8, 9 and 11 in the optical path is to focus the light from the LED chips onto the patient's pupil 12. For convenience, the cornea is not shown, and does not affect the raytrace greatly. The eye's pupil 12 is at the same plane as the exit pupil of the illumination optics and the entrance pupil of the imaging optics, both annotated 12 or 12c as well as they are optically similar features.

The wide and narrow imaging optics focus the light from the pupil 12 onto an aperture stop shown in Figure 3 as item 23, and Figure 4 as item 33; and which may comprise more than one transmitting area. The backwards projection of items 23 and 33 onto the pupil 12 defines an area of the pupil 12 that will illuminate the CCD camera chip, shown as item 29 in Figures 3 and 4. Light falling outside this area on pupil 12 will be vignetted by the stops, items 23 and 33. By arranging the geometry of the image of the LEDs focused on the pupil such that the LED light is offset sideways from the area of the pupil projected back through the imaging optics, ghost images from the LED illumination optics reflected into the imaging optics are largely prevented from reaching the imaging camera by the stops 23 and 33. Further reduction of the intensity of ghost images may be necessary by adding crossed linear polarisers into the illumination and imaging paths. One of these polarisers 61 is shown in Figure 1. The ghost reflections largely maintain the linear illumination polarisation, and therefore are blocked by the imaging polariser, but the retinal reflection scrambles the polarisation so that much of the image is transmitted through the linear polariser. Linear polarisers are readily available as stretched plastic sheets, and can be purchased cemented

between glass plates to maintain the optical quality of the reflected beam.

A glass plate 6 may be inserted into the beam with an opaque reticule evaporated onto it, which forms a scale image of the stops 23 and 33 used in the narrow and wide field of view imaging optics, when reflected off the innermost surface 11a of lens 11. The position of plate 6 is defined to be at the conjugate of the reflection of the stops 23 and 33 off that surface of lens 11. Any light from the LEDs that is reflected off the lens surface 11a is that would pass through the imaging apertures is therefore blocked by the opaque reticule on plate 6. The position of plate 6 and the size of the reticule obscurations is designed to present a minimum variation in light intensity projected onto the field of view covering the retina, which is typically less than 20%. This variation can be corrected by using software to multiply the captured image intensity by a number that varies across the field of view, and is calculated to compensate the change in effective optical gain from the LEDs to the imaging camera via a diffuse reflection off the retina.

The outermost surface 11b of lens 11 is designed to be concentric with the eye's pupil 12 so that the conjugates of ghost reflections of the stops in the imaging optics coincide exactly with the exit pupil 12. The cornea has a very short radius, so that reflections off it also form close to the exit pupil 12. Both sets of ghost reflections are therefore imaged by the imaging optics onto a position that is very close to the stops placed in the imaging optics. Because the images of the LEDs are designed to be laterally offset from the imaging stops, the ghost reflections will be vignetted by the imaging stops.

The near infra red LED can be selected as having a peak wavelength of around 850 nanometres wavelength. The red, green and blue LED package is widely available from a variety of sources with LED spectra that are well matched to the visible spectrum to provide a wide colour gamut. Adequate power output, to prevent noise in the image captured by the camera, can be achieved by obtaining LEDs with greater than 2 milliwatts rated light output per chip.

The illumination optics are combined with the imaging optics by means of beamsplitter 10 which redirects the reflected light from the eye downwards into the imaging optics. A suitable beamsplitter coating can be applied to the beamsplitter 10 to control the amount of light transmitted and reflected. The imaging optics may contain linear polarisers, in part to enable electro optical methods of switching between stereo apertures, which can also be used to absorb unwanted reflections from lens 11 and the patient's eye. This is feasible because the linear polarisations would transmit one preferred linear polarisation. Beamsplitter 10 would be coated with a polarising beamsplitter coating, which would reflect the preferred polarisation and transmit the orthogonal polarisation. Any specular reflections of the orthogonal polarisation would largely maintain the polarisation state, to be absorbed by the linear polarisers. Reflections from the retina have their polarisation state scrambled by the fine structure of the retina, so a substantial proportion of the reflected light is coupled from the orthogonal polarisation to the preferred polarisation, and transmitted through the linear polarisers.

The colour of light illuminating the retina, and therefore the colour of light reflected to the camera, is changed by switching the LEDs on and off in synchronisation with the camera electronics, so that any complete frame is illuminated with only one colour, but 4 sequential frames of different colours (red, green, blue and near infra red) are combined with software to generate a colour image.

Figure 2 shows the autorefraction optical system. A near infra red LED 13, similar to the one described in Figure 1, is used to illuminate a moving reticule 15 through lens 14. Reticule 15 comprises an array of circular apertures on an opaque background. Alternatively, it can be the negative image with opaque circular dots. It is moved along the optical axis by means of a motorised mechanical arrangement whose position is measured and monitored by software in a host computer. Simultaneously, the wide or narrow field of view imaging optics are used to view the image of the reticule 15 reflected off the retina.

The image of the reticule 15 is projected via lenses 53, 54 and 55, reflected off fold mirror 56 and moving fold mirror 57, into the illumination optical path towards the eye. Mirror 57 is moved under servo control into the optical path of the illumination optics to enable the autorefraction system, and out of the optical path to disable it. The effect of lenses 53, 54 and 55 is to compensate aberrations and focus in the illumination lenses 8, 9 and 11.

The host computer has a controller board to capture digital images from the imaging camera, and a motor control servo loop to move the motor by precise amounts and sense the motor position from a position feedback sensor. Each time an image is captured it is analysed to first detect the presence of the edges of the images of the dots, and then the rate of change of intensity, i.e. the edge contrast, is measure across the all of the edges so detected. The motor is driven by the host computer to maximise the edge contrast of the dots. For example, the motor servos could be driven through focus in discrete steps, and the measurements of the variation in edge contrast interpolated to calculate the best focus position in between the steps. Simultaneously the focus of the imaging optics is moved via a motor and servo control electronics, by moving the CCD camera chip 29 shown in Figure 3. The positions of the reticule 15 and CCD chip 29 are matched to the same conjugate at exit/entrance pupil 12, so that when reticule image on retina is focused, so is the reflected image on CCD chip 29. The positions of the reticule 15 and imaging optics are calibrated on assembly so that software in the host computer can calculate the focus geometry of the projected light at the exit/entrance pupil 12 that gives the best sharpness of the detected edges.

In the event of astigmatism in the patient's eye, the focus position of the best edge contrast will vary with the angle of the edges, so that at some positions one part of the circular edges of the dots will be in focus, and at other positions another part of the edge at a different angle will be in best focus. In order to measure astigmatism, the focus servos are driven through focus and the best sharpness of contrast for different angles of the edge are predicted by interpolation in image processing software in the PC. This information can then be

related directly to the focus condition of the patient's eye through knowledge of the optical characteristics of the autorefraction and imaging optics. The autorefraction system will calculate the eye's spherical focus error, its astigmatic error and the axis of astigmatism.

In the above described measurements, astigmatism correcting optics in the imaging optics will be set to produce zero correction of astigmatism in the imaging optical path. It is also possible to adjust the astigmatism correcting optics to null out astigmatism in the patient's eye as part of the measurement of astigmatism.

LED 13 is offset and positioned so as to avoid ghost reflections in the same way as described for Figure 1. The same method is used to suppress ghost images reflected into the imaging optics: light from the LED 13 is imaged onto pupil 12, and offset from the corresponding areas defined by stops 23 and 33 through which the imaging optics collect light. The same linear polariser 61 may be placed in the optical path to reduce the intensity of any light leaking between the stops 23 and 33, and the image of LED 13 at the pupil 12.

Figure 3 shows the wide field of view imaging optical system. Light is projected by the illumination optics shown in Figures 1 or 2 through the exit pupil and eye's pupil 12 onto the retina, where it is diffusely reflected back through the entrance pupil 12c.

The reflected image is projected by lens 11 onto beamsplitter 10, where it is reflected away from the illumination optics into the imaging optics. Lenses 16, 17, 18 and 19 help to project an image of stop 12c onto the aperture stop 23. Aperture stop 23 may incorporate a linear polariser that is crossed with respect to the linear polariser 61, to further suppress ghost images. Beamsplitter 42 is coated with a low reflectivity coating that reflects about 10% of the light from the field screening optics into the optical path but transmits about 90% of the light reflected from the retina. It therefore also reflects a small amount of light out of the imaging optical path. Beamsplitter 42 is a thin piece of glass, so it induces minimal non rotationally symmetrical optical aberrations in the optical path.

Two cylindrical lenses 20 and 21 are placed after beamsplitter 42. The tilted beamsplitter 42 will induce small amounts of astigmatism which can be compensated by offsetting the cylindrical lenses 20, 21 from their nominal positions. The cylindrical lenses 20 and 21 are moved in two separate movements to compensate astigmatism in the patient's eye, in conjunction with the focus movement of camera chip 29. The null position, where they induce zero astigmatism, occurs with a spacing of about 0.25mm between the two curved surfaces, the other surfaces being planar. This distance can be increased to aid the design and engineering of the mechanics by slightly altering the radius of curvature of one of the lenses using computer optimisation to calculate the new curve. This calculation will be obvious and without inventive step to an optical designer. The combination of spherical and astigmatic errors in the patient's eye comprise, in theory, a toroidal wavefront error from any point in the image. The term 'wavefront error' is a standard term used by any optical designer trained in the art. Moving the cylindrical lenses 20, 21 apart adds an amount of astigmatism to the wavefront error. Moving the CCD chip 29 can introduce a negative spherical wavefront error.

Moving lenses 20 and 21 apart can induce a positive amount of astigmatism which is combined with a negative amount of spherical wavefront error induced by moving CCD chip 29, so that the overall effect is a negative astigmatic wavefront change. This combination will be obvious to an optical designer by looking at the addition of spherical and astigmatic wavefront error polynomials. It is therefore possible to induce either positive or negative astigmatism with only positive astigmatism arising directly from the movement of lenses 20 and 21. The terms positive and negative as used here have arbitrary meanings, but have an opposite effect on the wavefront.

A large range of spherical wavefront error can be added to the astigmatic wavefront error by further movements of CCD chip 29. The major and minor axes of the toroidal wavefront can be set by rotating the combined sub assembly of lenses 20 and 21 about the optical axis 30. The focusing movement and cylindrical lens movements are under computer control through a servo system with three separate movements. Each

movement can be calibrated on manufacture to precisely control the optical effects. Position feedback sensors in all three servos can easily be read back into host computer software and used to calculate spherical focus, astigmatic correction and astigmatic axis of the patient's eye when best focus and astigmatism correction is achieved. The setting of best focus can either be done automatically from the autorefraction methods, or manually adjusted by the user.

In order to improve the compromise between cost and performance, the wide field of view imaging optics are designed to accept light through a 1.5mm diameter section of the pupil 12, that is centred on the optical axis. There will be some cross coupling of light from the illumination of the pupil from LEDs 1 and 2, which will be suppressed by the crossed linear polarisers in the illumination and imaging optics, i.e. items 61 and incorporated into stop 23.

The optical construction of lenses 20 and 21 are designed so that aberrations induced other than astigmatism are minimal.

The projected image, including any astigmatic wavefront error, is projected through lenses 22, 24, 25, 26, 27 and 28 onto the CCD chip 29. The apertures top 23 is a thin plate with an aperture shape etched or machined in it, that matches the illumination of the eye's pupil 12 and lens surface 11a as aforesaid, to reduce ghost images. The aperture stop 23 could be the same component as stop 33, shown in Figure 4, in the narrow field of view optical path.

The CCD camera chip 29 is typically a 1/2 inch CCD of standard format and interface with image capture board. In this embodiment, it has an 8mm diagonal active area.

The optical path from the eye's pupil 12c to the CCD chip 29 is computer optimised to maintain a variety of conditions, including telecentricity at the CCD camera chip 29. Telecentricity ensures that the image does not change size or shape as the CCD chip 29 is moved through its focus range. The principle of telecentric imaging is a standard technique that will be known by any optical designer.

The optical path from the eye's pupil 12c to the CCD camera chip 29 is designed for imaging over wavelengths including the visible spectrum and near infra red wavelengths out to about 850nm. The optics are corrected for both focus and magnification changes with wavelength over that range.

The optical resolution is superior to a 752 by 582 line CCD chip, which is a low cost standard CCD resolution. This value includes aberrations due to the cylindrical lenses 20 and 21.

The optical path is switched between wide field of view imaging, narrow field of view imaging and imaging of the pupil, for docking, by moving the lenses 22 through to 28 inclusive out of the way, and replacing them by a new set. Each of the three sets of optics is designed to focus on the same CCD chip 29 without moving the CCD chip 29 substantially from its focus setting equivalent to infinity conjugate at the eye. Either the host computer or the user will have to change the focus setting of the CCD chip 29 for other conjugates to accommodate changes in magnification between the three sets of optics, which means that a given spherical wavefront change requires different positions of the CCD chip 29. The setting of the astigmatism correction will not have to change as the magnification between the cylindrical lenses 20, 21 and the eye's pupil 12c does not change.

Figure 4 shows a raytrace through the narrow field of view stereo imaging optics. Light is reflected off the retina through the entrance pupil 12 and lens 11, reflected off beamsplitter 10, through lenses 16, 17, 18 and 19, through the fixed beamsplitter 42 and through cylindrical lenses 20 and 21. All of the optical path up to this point is identical to the wide field of view imaging optics, as shown in Figure 3, so that the effects of the cylindrical lenses 20, 21 are identical. The lenses 31, 32, 34, 35 and 35a project and focus the image through the electro-optic shutter 33 onto the CCD chip 29. The lenses 22, 24, 25, 26, 27 and 28 of figure 3 may be mounted in a single cell together with aperture 23; the cell being movable on a turret arrangement whose axis of rotation is parallel to the optical axis 30. The lenses 31, 32, 34, 35, 35a and electro optic shutter 33 may also be mounted in a second cell that

is fixed to the turret; rotating the turret therefore switches between the narrow and wide fields of view. An alternative configuration might leave the shutter 33 fixed as the wide field of view optics are moved into position, so that stop 23 and shutter 33 can be the same components.

The electro optic shutter 33 is formed by two liquid crystal cells between crossed polarisers, that can be electrically switched to transmit or absorb light. The dimensions of the liquid crystal cells are matched to the optical geometry of the aforesaid ghost reflections from the cornea and lens 11, so as to vignette the ghost images whilst transmitting the image reflected from the retina. The geometry of the cells is also arranged to provide two separate stereo images that can be analysed by computer software to generate a three dimensional image of the retina. The apertures of the cells might normally be two laterally offset circles, as are normally used to generate stereo pair images. This is a standard technique known by optical designers. The geometry of the projection of LEDs 1, 2 and 13 onto the pupil 12 is controlled so as not to reflect ghost images off the cornea into these offset circular apertures. The orientation of the linear polarisers is arranged so as to transmit light of an orthogonal polarisation to that transmitted by polariser 61, so as to reduce any residual ghost images further.

The CCD camera chip 29 is moved parallel to the optical axis 30 to focus the image from the retina, and in particular to offset variations in the patient's eye. This movement has a different scale than the corresponding movement for the wide field of view optics shown in Figure 3, as the focal length of the two optical paths is different. Because the movement of the CCD camera chip 29 is controlled through a servo system from a host computer, it is easy to generate matched focus movements for the wide and narrow fields of view, for example by generating separate look up tables controlling the focus drive signals for each configuration, so that on switching between the two configurations the focus setting relative to the patient's eye remains the same.

The optical path from the eye's pupil 12c to the CCD chip 29 is computer optimised, as with the wide field of view imaging optics, to ensure that the image does not change size or shape as the CCD chip 29 is

moved through its focus range. The principle of telecentric imaging is a standard technique that will be known by any optical designer.

Figure 5 shows a scale raytrace through the field screening optics. These are used to project a visible image to the patient that causes the patient to respond by looking at a target in the image. The docking optics shown in Figure 6 are used with the CCD camera chip 29 to simultaneously look at the patient's eye as it moves.

The field screening optics incorporate a lamp 36 of variable output brightness, again controlled from software in the host computer through a suitable electronic control hardware. A baffle arrangement is schematically shown as feature 37 which is a simple arrangement of blackened foil, plates or sheets to prevent light being directly projected from the lamp 36 to the patient's eye without reflecting off the Liquid Crystal Display (LCD) 38. The LCD 38 is controlled by software in the host computer to vary the target image. This is a simple shape that is brighter than the background illumination. The LCD 38 is controlled to switch pixels to generate a target image anywhere in the field of view, and to switch all the other pixels to a constant background level. The contrast between the background and the target, the size of the target and the position of the target are controlled by the LCD 38. The brightness of the target and background is controlled by the lamp 36. The target image is projected through lenses 39, 40 and 41, and reflected off beamsplitter 42. Beamsplitter 42 has a low reflectivity coating to maximise transmission of reflected light from the retina to the CCD camera chip 29. It is well within the capability of common tungsten halogen lamps to project sufficiently bright images despite the losses in the beamsplitter 42. The image reflected off beamsplitter 42 is transmitted through lenses 19, 18, 17 and 16, reflected off beamsplitter 10, and transmitted through lens 11 to form an illuminated pupil 43 that is larger than the entrance pupil of the patient's eye 12. The image is projected into the patient's eye through pupil 43 at an infinity conjugate.

The docking optics and CCD chip 29 are used to capture images of the patient's eye as it moves to view target images projected through the Field Screening optics shown in Figure 5. Host software is used to

capture the CCD camera images and perform fast edge detection algorithms to determine the edge of the image of the patient's iris. Due to the structure of the eye, this edge is the highest contrast part of the reflected docking image, and can be easily distinguished. The edge coordinates so calculated are mathematically averaged to define a centroid to the edges. The movement of the centroid defines the movement of the patient's eye in response to the field screening targets. The movement of the centroid can be linked to variations in the target position, contrast and brightness and the combined values stored on computer disc for later analysis. The host computer can use this information to generate a map over the field of view of visual function.

The narrow field of view optics imaging in this embodiment are designed to image over a wide waveband, from about 480nm to 850nm. There is a small variation in magnification over this range of wavelengths, which is acceptable as the narrow field of view imaging optics work primarily with near infra red light from the LEDs 1 and 13.

Figure 6 shows a scale raytrace through the docking optics. These are used to look at the iris of the patient's eye using reflected near infra red light from an array of LEDs 44 arranged around lens 11 to illuminate the patient's eye. The docking optics receives scattered and reflected light from the eye over the field of view 45, which is projected by lens 11, beamsplitter 10 and lenses 16, 17, 18 and 19 through beamsplitter 42 into cylindrical lenses 20 and 21. The cylindrical lenses 20 and 21 are moved in this configuration by their controlling servos to be close together so as to cancel each other out and project an image without astigmatism. They are shown in Figure 6 in the same section as in Figures 3 and 4. In Figure 6, the rays are shown to converge at the top and bottom of the field of view, which is 60% of the image diagonal. The full diagonal of the field of view is transmitted through the cylindrical lenses because they are longer in the direction perpendicular to the section of Figure 6, than their width as shown in Figure 6. The cylindrical lenses 20, 21 must be rotated by their servo system to align their long axis with the long axis of the CCD chip, so as to avoid vignetting. The rays shown in Figure 6 are imaged onto the top of the

active area of CCD chip 29. CCD chip 29 is substantially in the same position as when both the narrow and wide fields of view optics, shown in Figures 3 and 4, are both focused at infinity conjugate

The reflected docking image is projected through lenses 46 and 47 to stop 48, which serves to limit aberrations in the projected image. It is not necessary in this configuration to vignette ghost images, as the reflectivity of the outer structure of the eye is much higher than that of the retina, and the relative intensity of the ghost images is lower. Also, the ghost images help the operator to align the ophthalmoscope to the patient's eye.

The reflected docking image is projected through the stop 48, lenses 49, 50, 51 and 52 to the CCD camera chip 29.

Lenses 46, 47, 49, 50, 51 and 52, and stop 48, of the docking optics may be mounted in a cell that is located on the aforesaid turret, and moved into position by rotating the turret about the optical axis 30. The turret therefore has three positions controlled by a servo system that corresponds to either the wide field of view imaging optics, the narrow field of view imaging optics, or the docking optics being placed and aligned to the optical path.

It is implied that all the aforesaid lenses are coated with suitable anti reflection coatings that are an industry standard process.

A beam stop is positioned above beamsplitter 10 and fabricated from a black painted material to absorb unwanted light from the LEDs 1, 2 and 13 that is reflected from beamsplitter 10, and might otherwise reflect back to the CCD camera chip.

In general, it will be necessary to keep the patient's iris above 4mm in diameter, to enable sufficient aperture clearance to divide the pupil 12 into segments to avoid ghost images. To this end, a hood will be placed over the patient's head to shield their eyes from light stimuli, so inducing the dark response where the eye's pupil dilates. The near infra red LED illumination can be used to image the retina for autorefraction measurements, and for focusing up the wide or narrow field of view imaging optics, so maintaining the dark response as the eye does not respond to light of those wavelengths. A visible image of the eye can be taken by

illumination with light from the red, green and blue LEDs only for the period of three to five CCD frames, which is too short to overly affect the eye's dark response. The docking optics will also image light reflected off the eye from near infra red LEDs.

A raytrace through the combined raytrace of the field screening and docking optics is shown in Figure 7. The LEDs 44 illuminate the eye. Light scattered and reflected from the eye is collected along the ray paths shown through beamsplitter 42 into the docking optics. Ghost images from the reflections of the LEDs 44 that disturb the patient can be avoided if the LEDs 44 emit infra red light only. The lamp 36 illuminates the LCD 38, which reflects light along the ray paths shown to illuminate the eye. Reflective LCDs are readily available at sizes and resolutions suitable for this application.

A raytrace through the combined illumination and wide field of view imaging optics is shown in Figure 8. The moving mirror 57 can be moved to block off the autorefraction light path. LEDs 1 and 2 illuminate the eye through pupil 12. Light is reflected off the retina back through pupil 12, it is reflected off beamsplitter 10, and through the imaging optics to CCD chip 29. The field screening optics can be used to display a target to the patient; asking the patient to view the target will control their direction of gaze and enable different segments of the retina to be imaged. In general, to keep the patient's iris open above 4mm diameter, it will be necessary to take all images using near infra red LED illumination. The wide field of view imaging optics can be used to view the autorefraction image projected onto the retina by moving mirror 57 into the illumination beam.

A raytrace through the combined illumination, autorefraction and narrow field of view / stereo imaging optics is shown in figure 9. The system is switched between autorefraction measurements and imaging by moving mirror 57 into and out of the illumination beam. When in the beam, it totally obstructs the illumination light from LEDs 1 and 2. It is preferred to use the narrow field of view optics to measure autorefraction as they are more sensitive to focus errors than the wide field of view optics. The stereo shutter can have both apertures open or one aperture

open for normal viewing of the retina, either to take autorefraction measurements with the moving mirror 57 in place to illuminate the eye with the autorefraction reticule; or with moving fold mirror in the closed position to view light from LEDs 1 and 2 reflected off the retina.

Alternatively, with the moving fold mirror 57 obstructing the autorefraction beam, the eye can be illuminated with the LEDs 1 or 2 and the stereo shutter used to capture stereo pair images of the retina, e.g. from the optic disc. The patient's gaze direction can be controlled as with the wide field of view imaging by displaying a target through the field screening optics to the patient. In general, to keep the patient's iris open above 4mm diameter, it will be necessary to take all images using near infra red LED illumination.

Figure 10 is a scale diagram of the optical system showing how the optical components are positioned relative to each other. They are all arranged so to be bisected by the plane of the paper, the diagram forming a section through the optical design, about which it is symmetrical.

Other arrangements will be obvious to an optical designer by rotating the beamsplitters and mirrors. The space taken by the optical components is sufficiently small to enable a complete ophthalmoscope product that can fit on a table with minimum floor space usage. A scale bar is included in Figure 10. The turret arrangement is signified by showing three separate optical sub assemblies, 58, 59 and 60 comprising the separate groups of lenses that view through the common optical path, each separately imaging the wide field of view images, the narrow field of view and stereo images, and the docking images. The optical system may be switched between these three configurations by rotating the three lens sub assemblies on a mechanical turret whose axis is parallel to the optical axis 30. Three separate stops 23, 33 and 48 can be incorporated into the separate sub assemblies 58, 59 and 60 to control the light paths specifically for the configuration corresponding to that sub assembly. They can all be used to suppress ghost reflections, incorporate a linear polariser, and in the case of stop 33, act as a stereo shutter.

All of the lenses may be coated with antireflection coatings to improve performance in the usual way.

Image processing software in the host computer will combine the red, green, blue and near infra red images together. The intensity of the red, green, blue and near infra red images will differ due to the varying optical transmission at different wavelengths, and different LED outputs. The ophthalmoscope may be calibrated on manufacture to store calibration factors in software, or on an EPROM memory chip, that are used to multiply the intensity of the captured images in software, so that an accurate colour rendition of the retina can be achieved.

Binocular disparity between the left and right eyes can be measured using the aforementioned method of placing a simple lens and light source combination either side of the lens 11, which are used to illuminate the eye not being tested. The docking optics can be illuminated with near infra red light and used to detect movements of the eye under test and changes to its pupil diameter using the automatic detection and measurement of the edge of the pupil, as described for the field screening measurements.

The cylindrical lenses 20, 21 may be mounted in cells, one of which moves, with stops featured in the cell design that prevents the curved surfaces of the lenses contacting each other. The cylindrical lenses can easily be slightly redesigned by an optical designer by changing just one of the cylindrical curvatures, so that the distance between the cylindrical lenses 20, 21 corresponding to zero induced astigmatism is increased.

The following coatings are described in the open literature, and are generally available as films that can be vacuum evaporated onto the components.

The coating on beamsplitter 3 may be a dichroic coating, or a broad band equal reflectance and transmitting coating.
The coating on beamsplitter 10 may be a broadband polarising beamsplitter coating.
Beamsplitter 42 may be uncoated as it will reflect enough light.
Mirrors 56 and 57 may be coated with front surface mirror coatings.

Stop 6 shown in the illumination optics Figure 2 can be manufactured by evaporating a metal film over the area of the substrate to be blocked. The dimensions of this area can be ascertained by any optical designer by tracing rays back from stops 23 and 33, via a reflection off lens surface 11a, to the stop 6 substrate.

In use, the docking optics can be used to align the ophthalmoscope to the patient's eye, by moving the whole ophthalmoscope vertically and horizontally in three dimensions, and the docking optics left active whilst field screening and binocular disparity measurements are taken. The imaging optics can be switched in to capture images of the retina, stereo images of the optic disc, and autorefraction measurements before the patient moves their eye. The docking optics can be switched back into the optical path between these measurements to enable the realignment of the ophthalmoscope to the patient's eye. The patient may have a head rest to facilitate keeping their eye stationary during the measurements. The field screening display optics can be used to display a fixation target to the patient, to further aid them keeping their eye stationary.

In any embodiment described, the LEDs can be replaced by laser diodes or lamps in an obvious manner. Also in any embodiment, the CCD camera chip can be replaced by any other device capable of capturing an image onto computer format.

The embodiments described above are easily transformed by reversing the reflection and transmission of beamsplitter 10, i.e. by making the illumination light reflect off it and the imaging light transmit through it. Generally the optical principles and design remain the same with a variety of configuration modifications, derived by changing the position or function of the beamsplitters and mirrors, or adding new beamsplitters or mirrors. The essential invention is in designing matched optical paths, enabling multiple functions using common components. The variations in mirrors and beamsplitters are obvious developments.

The spherical focus movement, described in the above embodiments as occurring when the camera is moved, can also be achieved by moving one or more lenses, with or without moving the camera, with one or more movements.

CLAIMS

1. An ophthalmoscope optical system adapted for use in examining a patient's eye for a multiplicity of defects, the system comprising a plurality of disparate groups of optical components each associated, in use, with the identification of a specific defect of the patient's eye, characterised in that each group of optical components is arranged within the system for sequential movement between an inoperative position and an operative position, in which operative position each group of optical components is aligned with fixed components of the system to facilitate, when the system is in use, the examination of the patient's eye for a specific defect.

2. An ophthalmoscope optical system according to Claim 1 characterised in that the groups of optical components are each mounted for movement on a rotating turret.

3. An ophthalmoscope optical system according to Claim 2 characterised in that the turret comprises location means for accurately positioning each group of optical components one at a time in alignment with fixed components of the system to facilitate, when the system is in use, the examination of the patient's eye for a specific defect.

4. An ophthalmoscope optical system according to any one of Claims 1 to 3 comprising multiple optical configurations that illuminates the eye by projecting light from an illumination source into the patient's pupil and divides the light reflected from the retina by means of a beamsplitter in the optical path; and comprises optical systems that share common optical components to perform wide field of view imaging over more than 35 degrees diagonal field of view, and to perform an alignment function to the patient by imaging the patient's pupil; both imaging functions using the same camera device, which may or may not be a CCD chip; the ophthalmoscope also incorporating an optical system that shares common components with the imaging optics to display an image suitable for inducing patient response and eye movement; the ophthalmoscope also incorporating a mechanical arrangement to change the optical path between the wide field of view and docking optical systems.

5. An ophthalmoscope optical system according to any one of Claims 1 to 3 comprising multiple optical configurations that illuminates the eye by projecting light from an illumination source into the patient's pupil and divides the light reflected from the retina by means of a beamsplitter in the optical path; and comprises optical systems that share common optical components to perform wide field of view imaging over more than 35 degrees diagonal field of view at the eye, and to perform an alignment function to the patient by imaging the patient's pupil; both imaging functions using the same camera device, which may or may not be a CCD chip; the ophthalmoscope also incorporating an optical system that shares common components with the imaging optics to display an image suitable for inducing patient response and eye movement; the ophthalmoscope also incorporating a device for changing the illumination optical path to illuminate the eye by a light source through a moving reticule that can be viewed through the wide field of view optics to generate measurements of refraction errors in the patient's eye; the ophthalmoscope also incorporating a mechanical arrangement to change the optical path between the wide field of view and docking optical systems.

6. An ophthalmoscope optical system according to Claims 4 and 5 where the wide field of view optics are replaced by narrower field of view imaging optics with a field of view under 35 degrees diagonal at the eye.

7. An ophthalmoscope optical system according to Claims 4 or 5 where the wide field of view optics are combined with an alternative optical configuration having a narrower field of view imaging optics, both optical systems sharing common optical components, and with the moving mechanical arrangement extended to change the optical path magnification and focal length by moving optical components to switch between the narrow and wide field of view optical paths.

8. An ophthalmoscope optical system according to Claims 4, 5, 6 or 7 which incorporates the additional illumination optical path to illuminate the eye with a reticule; which shares data with a computer that analyses the images captured from the camera sensor, and controls the focus of the

reticule in the illumination optics and the focus movement in the wide or narrow field of view imaging optics via a motor control servo loop to move the motor by precise amounts; and senses the motor position from a position feedback sensor; the computer having image processing software that analyses the image of the reticule captured from the camera sensor to first detect the presence of the edges of the images of the dots, and then the edge contrast; the computer comparing the edge contrast with the position of the reticule and said camera sensor to calculate refraction errors in the patient's eye.

9. An ophthalmoscope optical system according to any one of Claims 4, 5, 6, 7 and 8 comprising a lamp of variable output brightness that illuminates a reflective display device; the lamp brightness being controlled by a host computer; the display device being controlled by software in the host computer to vary a target image contrast; the position, brightness and contrast of the target image being varied by software in the host computer; the target image being projected into the patient's eye through the optical system; the optical system incorporating a beamsplitter that enables the camera device to view the movement of the patient's eye in response to the target image.

10. An ophthalmoscope optical system according to Claim 9 in which the host computer analyses the image captured with the camera device to perform fast edge detection algorithms to determine the edge of the image of the patient's iris; the edge coordinates so calculated being mathematically averaged to define a centroid to the edges; the movement of the centroid being linked to variations in the target position, contrast and brightness by software in the computer and the combined values stored on computer disc or memory for later analysis.

11. An ophthalmoscope optical system according to any one of Claims 4 to 10 where the aforesaid display device is used to display a target image to the patient; the patient being asked to look at the target; and the target being moved to control the patient's direction of gaze.

12. An ophthalmoscope optical system according to any one of Claims 4 to 11 where the eye's pupil or retina, or any other part of the eye, is illuminated and viewed with near infra red light in order to avoid stimulating the patient's eye, and in order to keep the patient's iris substantially dilated.

13. An ophthalmoscope optical system according to any one of Claims 4 to 12 where the optics used to project the image from the display device, and the display device, are removed from the design.

14. An ophthalmoscope optical system according to any one of Claims 4 to 13 where the field of view imaging optics contain a stereo switching aperture enabling the capture of stereo image pairs by the camera.

15. An ophthalmoscope optical system according to any one of Claims 4 to 14 where the illumination optical path containing means of combining light from more than one light source, each light source emitting a different range of wavelengths; the colour of light illuminating the retina, and therefore the colour of light reflected to the camera device, being changed by switching the light source on and off in synchronisation with the camera electronic system, so that any complete frame is illuminated with only one colour, but sequential frames of different colours are captured.

16. An ophthalmoscope optical system according to Claim 15 where the captured colour images are stored in a computer memory and processed by image processing software to combine the separate images into a colour image, which may or may not incorporate a false colour representation of the near infra red image.

17. An ophthalmoscope optical system according to any one of Claims 4 to 16 where a second and third optical channel are added either side of the aforesaid optical system to illuminate the untested eye with a visible light source to stimulate binocular effects in the patient's eyes, whilst the aforesaid optics and camera device are used to view the changes to the tested eye.

18. An ophthalmoscope optical system according to Claim 17 where computer software analyses the images captured by the camera device using fast edge detection algorithms to determine the edge of the image of the patient's iris; the edge coordinates so calculated being mathematically averaged to define a centroid to the edges; the movement of the centroid being used to define the response the tested patient's eye to light projected into the patient's untested eye.

19. An ophthalmoscope optical system according to any one of Claims 4 to 18 where the geometry of the illumination beam being projected into the eye by the light sources and associated optical path is arranged to reflect off the cornea in such a way as to be vignetted by stops in the imaging optical path.

20. An ophthalmoscope optical system according to any one of Claims 4 to 19 where one or more stops or reticules are inserted into the illumination optical path with an opaque shape incorporated on them, which forms a scale image of the stops in the imaging optics when reflected off surfaces of lenses in the illumination optical path, which lie between the beamsplitter which separates the illumination and imaging optical paths and the eye; the stops or reticules being positioned in the optical path substantially at the focus of the reflections of the imaging optics stops when projected back into the illumination optical path.

21. An ophthalmoscope optical system according to Claim 20 where the images produced from the camera device are processed in computer software by multiplying the output from each pixel by a number to represent the variation in transmission caused by the stops or reticules across the field of view, so as to generate a corrected image with uniform optical gain between the light sources and the camera device via reflection off the retina.

22. An ophthalmoscope optical system according to any one of Claims 4 to 21 where the outermost lens surface is designed to be concentric with the eye's pupil so that the conjugates of ghost reflections of the stops in the imaging optics coincide exactly with the exit pupil.

23. An ophthalmoscope optical system according to any one of Claims 4 to 22 where crossed linear polarisers are incorporated in the illumination and imaging optical path, which may or may not be integrated into the imaging optics apertures, to suppress ghost images reflected off the eye or lenses, whilst still transmitting a substantial proportion of the light reflected from the retina.

24. An ophthalmoscope optical system according to Claim 23 where the polarisation of the beamsplitter which separates the illumination and imaging optical paths is used to selectively illuminate the eye with a higher brightness beam and simultaneously increase the light level imaging through to the camera, by matching the polarisation properties of the beamsplitter to the orientation of the linear polarisers.

25. An ophthalmoscope optical system according to any one of Claims 4 to 24 where cylindrical lenses are included in the imaging optical paths and are moved with respect to each other to compensate astigmatism in the eye.

26. An ophthalmoscope optical system according to Claim 25 where one or more rotationally symmetrical lens or the camera or a combination of both is moved to compensate spherical refraction error in the eye, the combination of such movements with the cylindrical lens movements being controlled to generate arbitrary toroidal wavefronts in the imaging beams that compensate toroidal refraction errors in the eye.

27. An ophthalmoscope optical system according to any one of Claims 4 to 26 where a hood is placed over the patient's head to shield their eyes from light stimuli, so inducing the dark response where the eye's pupil dilates.

28. An ophthalmoscope optical system according to any one of Claims 4 to 27 where the imaging optics used view the eye's pupil are omitted from the design.

29. An ophthalmoscope optical system according to any one of Claims 4 to 28 where the optical path at the camera device is arranged to be telecentric for one or more optical configurations that focus the retina onto the camera device.

30. An ophthalmoscope optical system according to any one of Claims 4 to 29 where the optical system is rearranged by rearranging the beamsplitter which separates the illumination and imaging optical paths to reflect the illumination optical paths and transmit the imaging optical paths.

31. An ophthalmoscope optical system according to any one of Claims 4 to 30 where the optical system is rearranged by adding one or more plane mirrors or beamsplitters into the optical paths, or rotating one or more beamsplitters in the optical paths.

AMENDED CLAIMS

[received by the International Bureau on 17 July 2001 (17.07.01); original claims 1-31 replaced by new claims 1-34 (7 pages)]

1. An ophthalmoscope optical system adapted for use in examining a patient's eye for a multiplicity of properties, the system comprising a plurality of disparate groups of optical components, characterised in that some groups of optical components are arranged within the system for sequential movement between an inoperative position and an operative position, in which operative position each group of optical components is aligned with fixed components of the system to facilitate at least three of the following functions of wide field of view retinal imaging, narrow field of view retinal imaging, stereo retinal imaging, the measurement of the patient's response to a variable position target, the measurement of the refractive properties of the patient's eye, the imaging of the area around the patient's iris and movements of the patient's eye as light is shone into the other eye.

2. An ophthalmoscope optical system according to claim 1, the system comprising a plurality of disparate groups of optical components, which facilitate at least four of the following functions of wide field of view retinal imaging, narrow field of view retinal imaging, stereo retinal imaging, the measurement of the patient's response to a variable position target, the measurement of the refractive properties of the patient's eye, the imaging of the area around the patient's iris and movements of the patient's eye as light is shone into the other eye.

3. An ophthalmoscope optical system according to claim 1, the system comprising a plurality of disparate groups of optical components, which facilitate at least five of the following functions of wide field of view retinal imaging, narrow field of view retinal imaging, stereo retinal imaging, the measurement of the patient's response to a variable position target, the measurement of the refractive properties of the patient's eye, the imaging of the area around the patient's iris and movements of the patient's eye as light is shone into the other eye.

4. An ophthalmoscope optical system according to claim 1, the system comprising a plurality of disparate groups of optical components, which facilitate at least six of the following functions of wide field of view retinal imaging, narrow field of view retinal imaging, stereo retinal imaging, the measurement of the patient's response to a variable position target, the measurement of the refractive properties of the patient's eye, the imaging of the area around the patient's iris and movements of the patient's eye as light is shone into the other eye.

5. An ophthalmoscope optical system according to claim 1, the system comprising a plurality of disparate groups of optical components, which facilitate all of the following functions of wide field of view retinal imaging, narrow field of view retinal imaging, stereo retinal imaging, the measurement of the patient's response to a variable position target, the measurement of the refractive properties of the patient's eye, the imaging of the area around the patient's iris and movements of the patient's eye as light is shone into the other eye.

6. An ophthalmoscope optical system according to any preceding claim that illuminates the patient's retina from light sources that are focused close to the eye's pupil, and collects light reflected from the retina through one or more apertures, and is arranged so that the virtual images of the light sources and apertures are substantially in the same position as the eye's pupil.

7. An ophthalmoscope optical system according to any preceding claim that forms an image of the retina or iris on a single image capture device, such as a Charge Coupled Device (CCD) camera.

8. An ophthalmoscope optical system according to any preceding claim where the illumination optical path incorporates means of combining light from more than one light source, each light source emitting a different range of wavelengths; the colour of light illuminating the retina, and therefore the colour of light reflected to the image capture device, being changed by switching the light source on and off in synchronisation with said image capture device, so that any complete image is illuminated with only one colour, but sequential images of different colours are generated.

9. An ophthalmoscope optical system according to claim 8 in which red, green, blue and near infra red light sources are used to illuminate the eye and the resultant images are combined for display to the user.

10. An ophthalmoscope optical system according to claim 8 in which red, green and blue light sources are used to illuminate the eye and the resultant images are combined for display to the user.

11. An ophthalmoscope optical system according to any preceding claim that incorporates one or more Light Emitting Diodes (LEDs) as the light source, where the LEDs are focused substantially in the region of the eye's pupil.

12. An ophthalmoscope optical system according to any preceding claim where the eye's pupil or retina, or any other part of the eye, is illuminated and viewed with near infra red light in order to avoid stimulating the patient's eye, and in order to keep the patient's iris substantially dilated.

13. An ophthalmoscope optical system according to any preceding claim that incorporates fixed optical elements closest to the patient's eye that include at least one beamsplitter.

14. An ophthalmoscope optical system according to any preceding claim that incorporates cylindrical lenses to correct for astigmatism in the patient's eye, said cylindrical lenses being moved to compensate for variable amounts of astigmatism.

15. An ophthalmoscope optical system according to any preceding claim that tests one eye for binocular response by illuminating the other eye with a light source that is projected into that other eye, and projects an image of the eye under test to view changes induced in it.

16. An ophthalmoscope optical system according to claim 15 that illuminates the untested eye by projecting light through one or more optical elements.

17. An ophthalmoscope optical system according to any preceding claim in which the optical elements are adapted for movement under computer control.

18. An ophthalmoscope optical system according to any preceding claim where the optics are adapted to be suitable for computer processing of images to measure the 3 dimensional shape of the optic disc.

19. An ophthalmoscope optical system according to any preceding claim where the optics are adapted to be suitable for computer processing of images to measure refraction in the patient's eye.

20. An ophthalmoscope optical system according claim 19 which incorporates an illumination optical path to illuminate the eye with a reticule; and which is arranged to generate an image of the light reflected by the retina that can be analysed by a computer, the position of the reticule in the illumination optics and the focus movement in the imaging optics being adjusted to project the reticule pattern and view its reflected image with various amounts of defocused light, the optical system being suitably arranged so that said computer utilises image processing software to analyse the image of said reticule to calculate refraction errors in the patient's eye.

21. An ophthalmoscope optical system according to any preceding claim where the optics are adapted to be suitable for computer processing of images to measure the movement of the patient's eye in response to stimuli projected through the field screening optics.

22. An ophthalmoscope optical system according to claim 21 where the docking optics and field screening optics are used simultaneously.

23. An ophthalmoscope optical system according to either claim 21 or 22 that incorporates a lamp of variable output brightness that illuminates a reflective display device; the lamp and display being suitably arranged to project an image of varying position, brightness and contrast into the patient's eye through the optical system; the optical system incorporating a beamsplitter that enables an image capture device to view the movement of the patient's eye in response to said target image.

24. An ophthalmoscope optical system according to claim 23 where the aforesaid display device is used to display a target image to the patient; the patient being asked to look at the target; and the target being moved to control the patient's direction of gaze.

25. An ophthalmoscope optical system that uses the switching of polarising liquid crystal cells to generate stereo images.

26. An ophthalmoscope optical system according to any preceding claim that has telecentric illumination of the CCD.

27. An ophthalmoscope optical system according to any preceding claim in which a beamstop is placed in the vicinity of the optical elements that are close to the eye to absorb unwanted light.

28. An ophthalmoscope optical system according to any preceding claim where the geometry of the illumination beam being projected into the eye by the light sources and associated optical path is arranged to reflect off the cornea in such a way as to be controlled and vignetted by stops in the imaging optical path.

29. An ophthalmoscope optical system according to claim 28 where one or more stops or reticules are inserted into the illumination optical path with an opaque shape incorporated on them, which forms a scale image of the stops in the imaging optics when reflected off surfaces of lenses in the illumination optical path, which lenses lie between the beamsplitter, which separates the illumination and imaging optical paths, and the eye; said stops or reticules being positioned in the optical path substantially

at the foci of the reflections of said imaging optics stops when projected back into the illumination optical path.

30. An ophthalmoscope optical system according to claim 29 where the images produced from said camera device are processed in computer software by multiplying the output from each pixel by a number to represent the variation in transmission caused by said stops or reticules across the field of view, so as to generate a corrected image with uniform optical gain between the light sources and the image capture device via reflection off the retina.

31. An ophthalmoscope optical system according to any preceding claim where the light sources are focused close to the pupil of the eye; and one or more surfaces of lenses in the illumination optical path, which lie between the beamsplitter, which separates the illumination and imaging optical paths, and the eye, are arranged to be substantially concentric with the eye's pupil; so that the conjugates of ghost reflections of said light sources from said lenses are focused substantially at the same place as the virtual image of the pupil of the eye.

32. An ophthalmoscope optical system according to any preceding claim where crossed linear polarisers are incorporated in said illumination and imaging optical path, which may or may not be integrated into the imaging optics apertures, to suppress ghost images reflected off the eye or lenses, whilst still transmitting a substantial proportion of the light reflected from the retina.

33. An ophthalmoscope optical system according to claim 32 where the polarisation of the beamsplitter, which separates the illumination and imaging optical paths, is used to selectively illuminate the eye with a higher brightness beam and simultaneously increase the light level imaging through to the camera, by matching the polarisation properties of said beamsplitter to the orientation of the linear polarisers.

34. An ophthalmoscope optical system according to any preceding claim where a hood is placed over the patient's head to shield their eyes from light stimuli, so inducing the dark response in which the eye's pupil dilates.

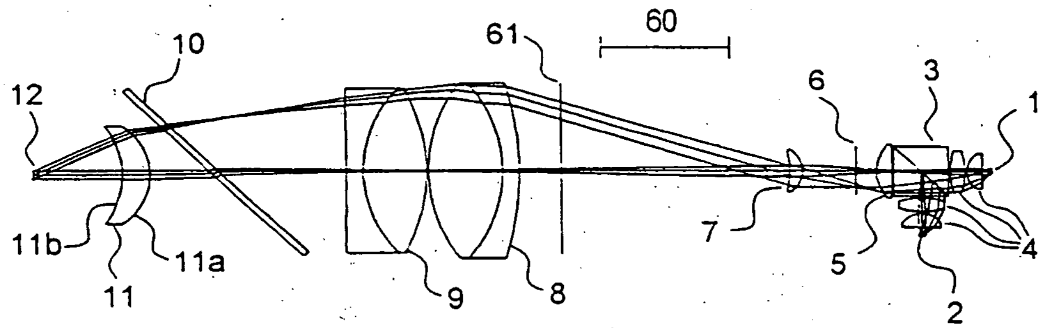


Figure 1.

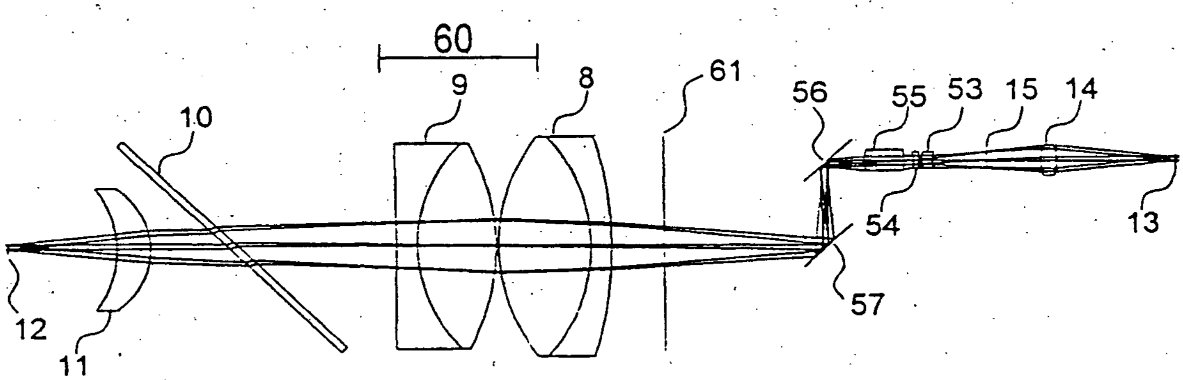


Figure 2.

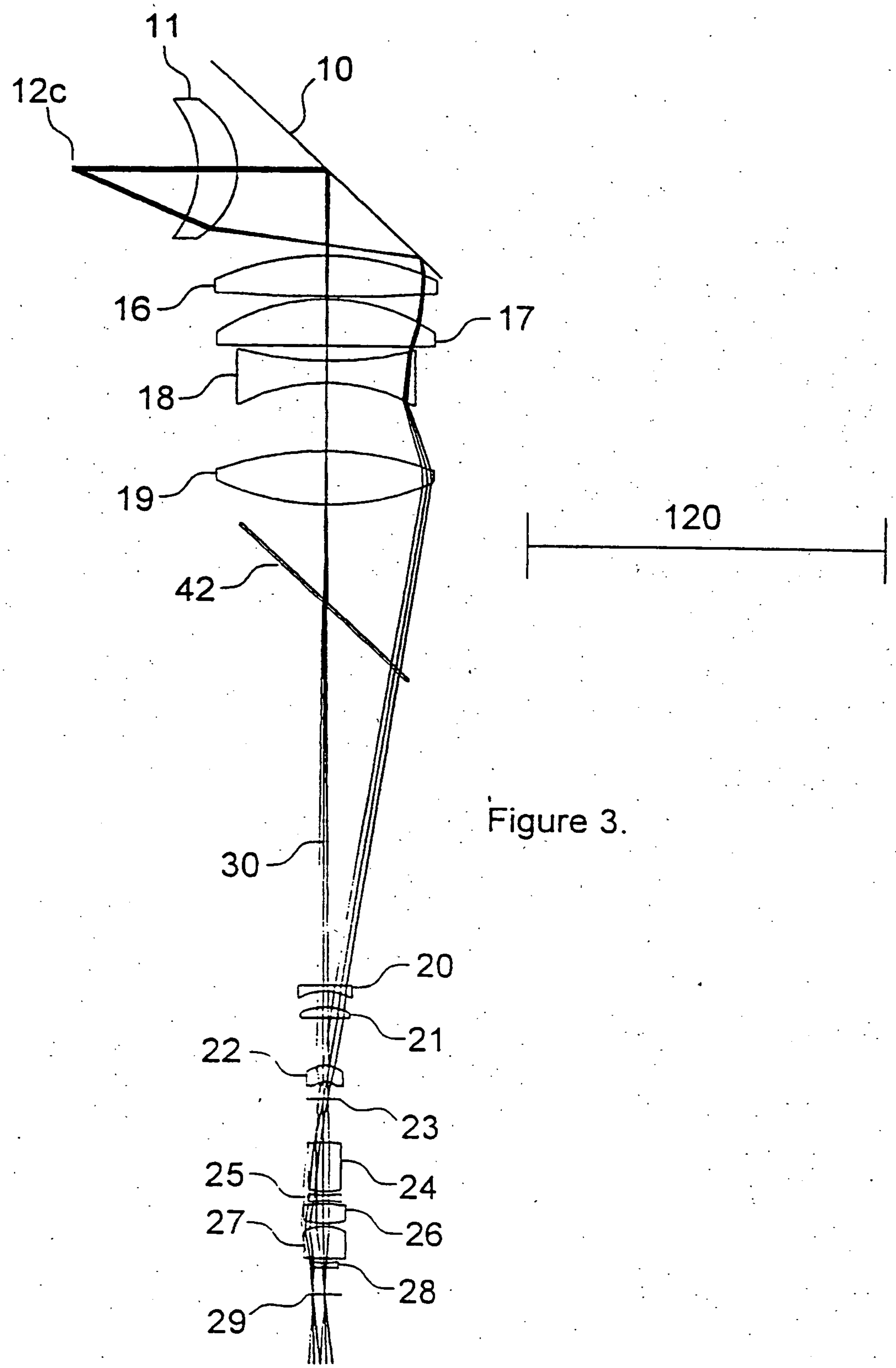


Figure 3.

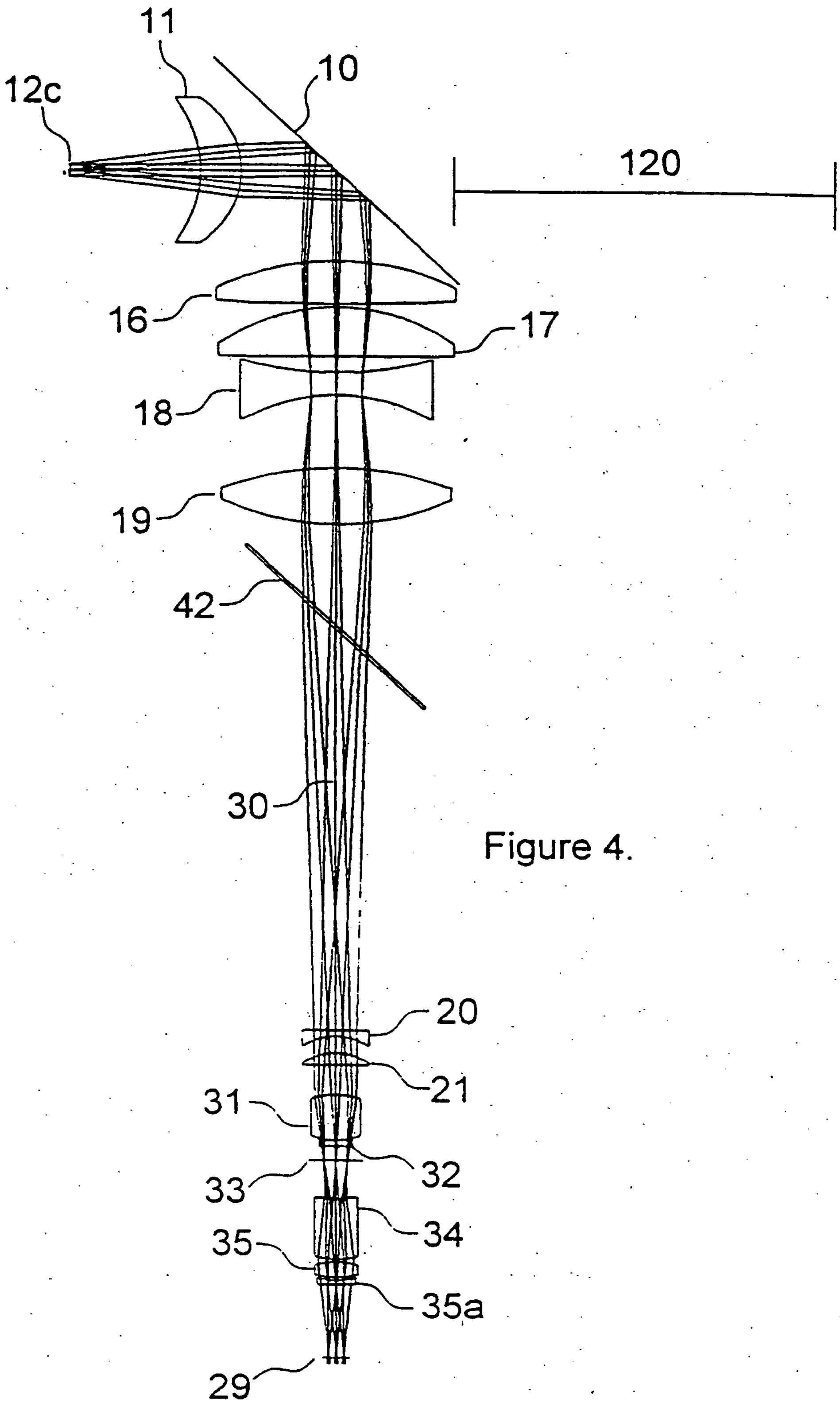


Figure 4.

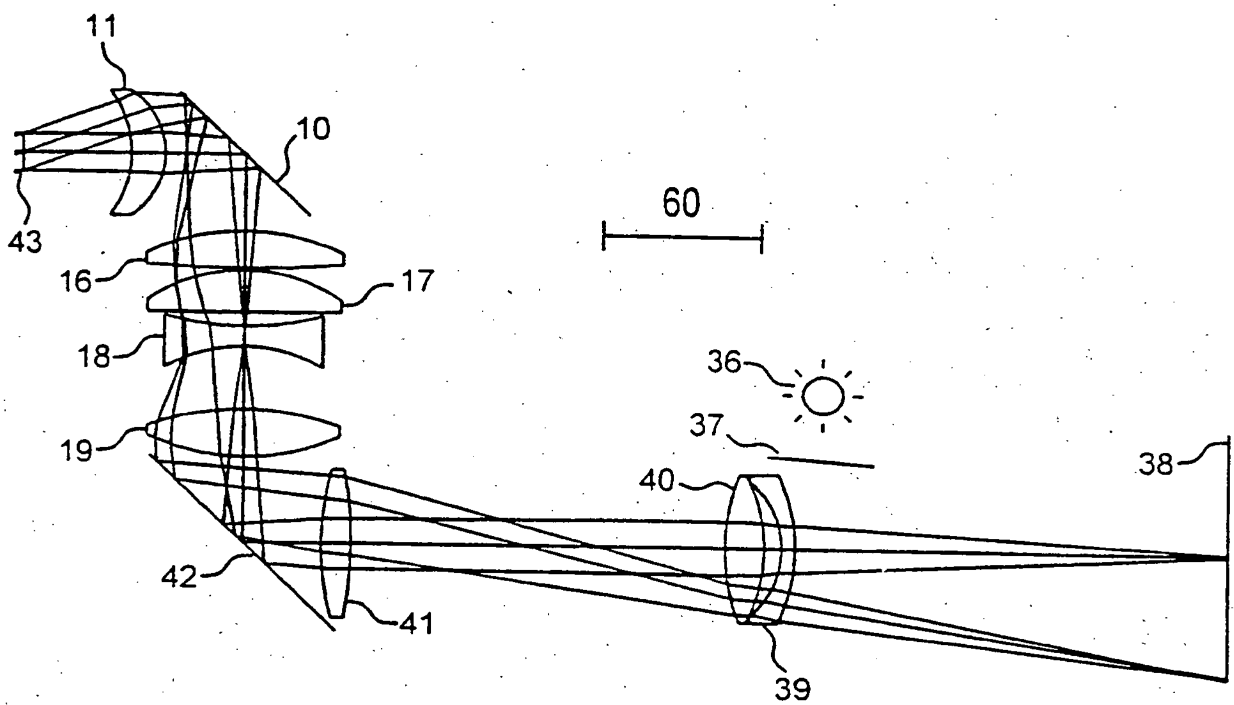


Figure 5.

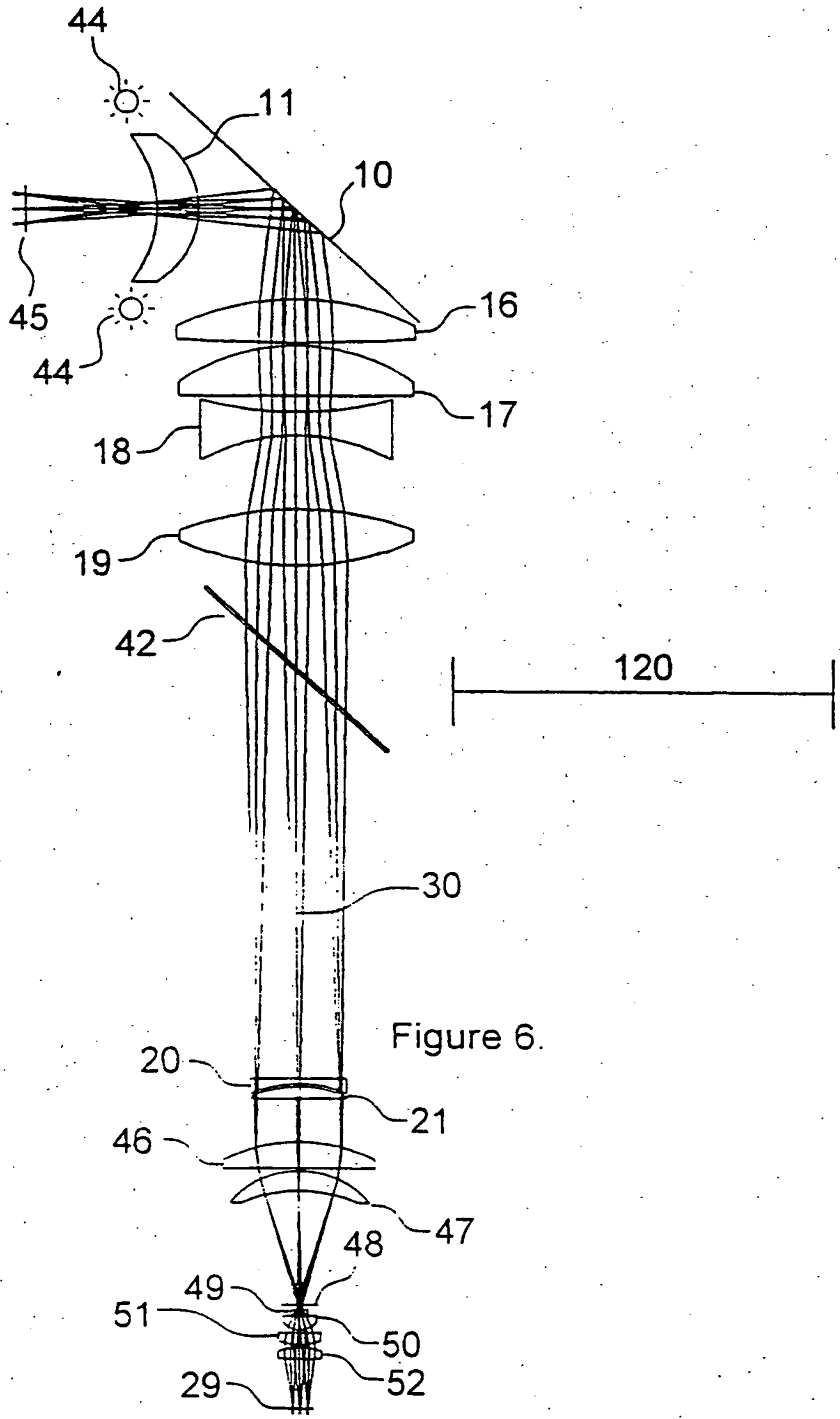


Figure 6.

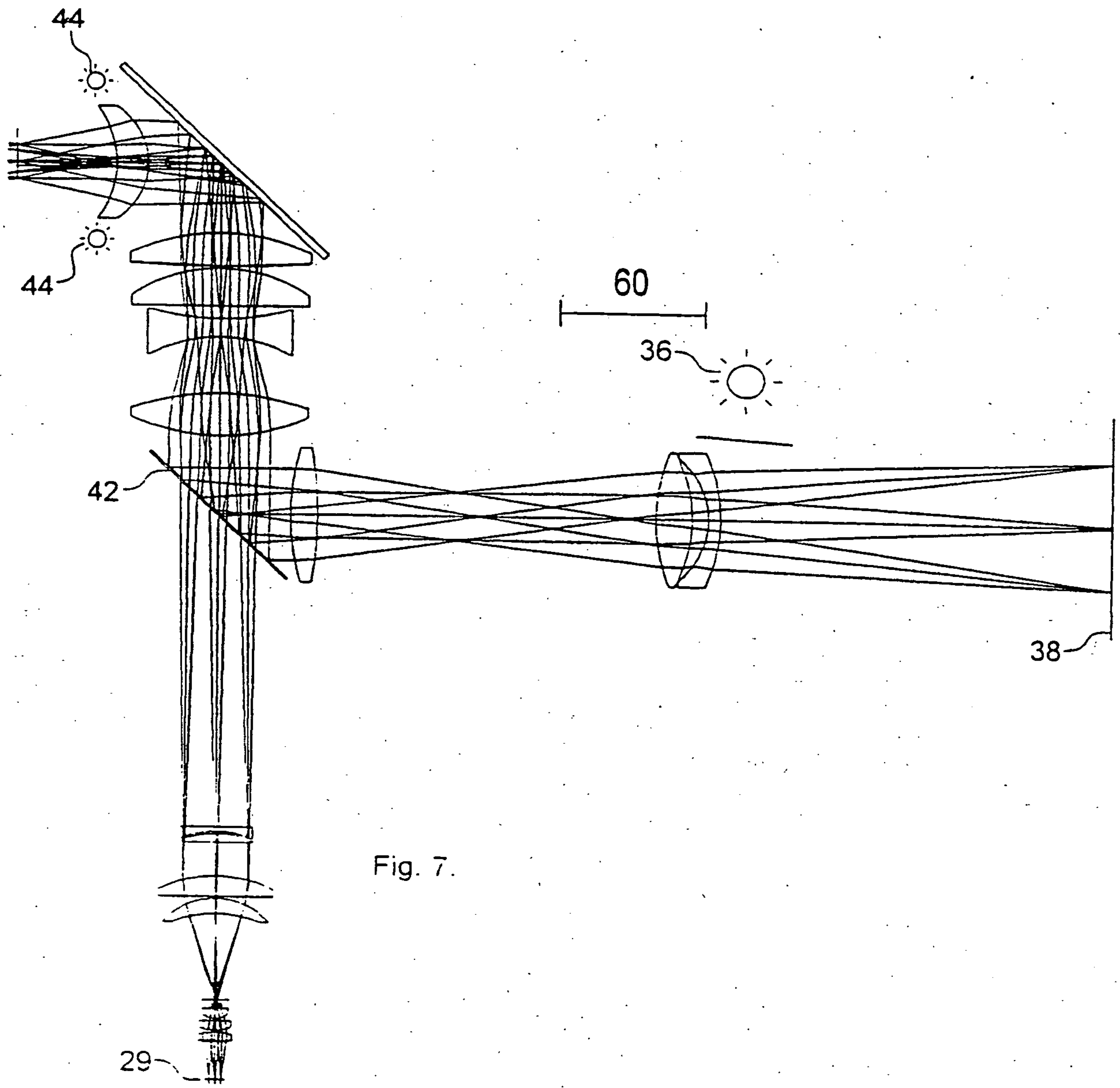


Fig. 7.

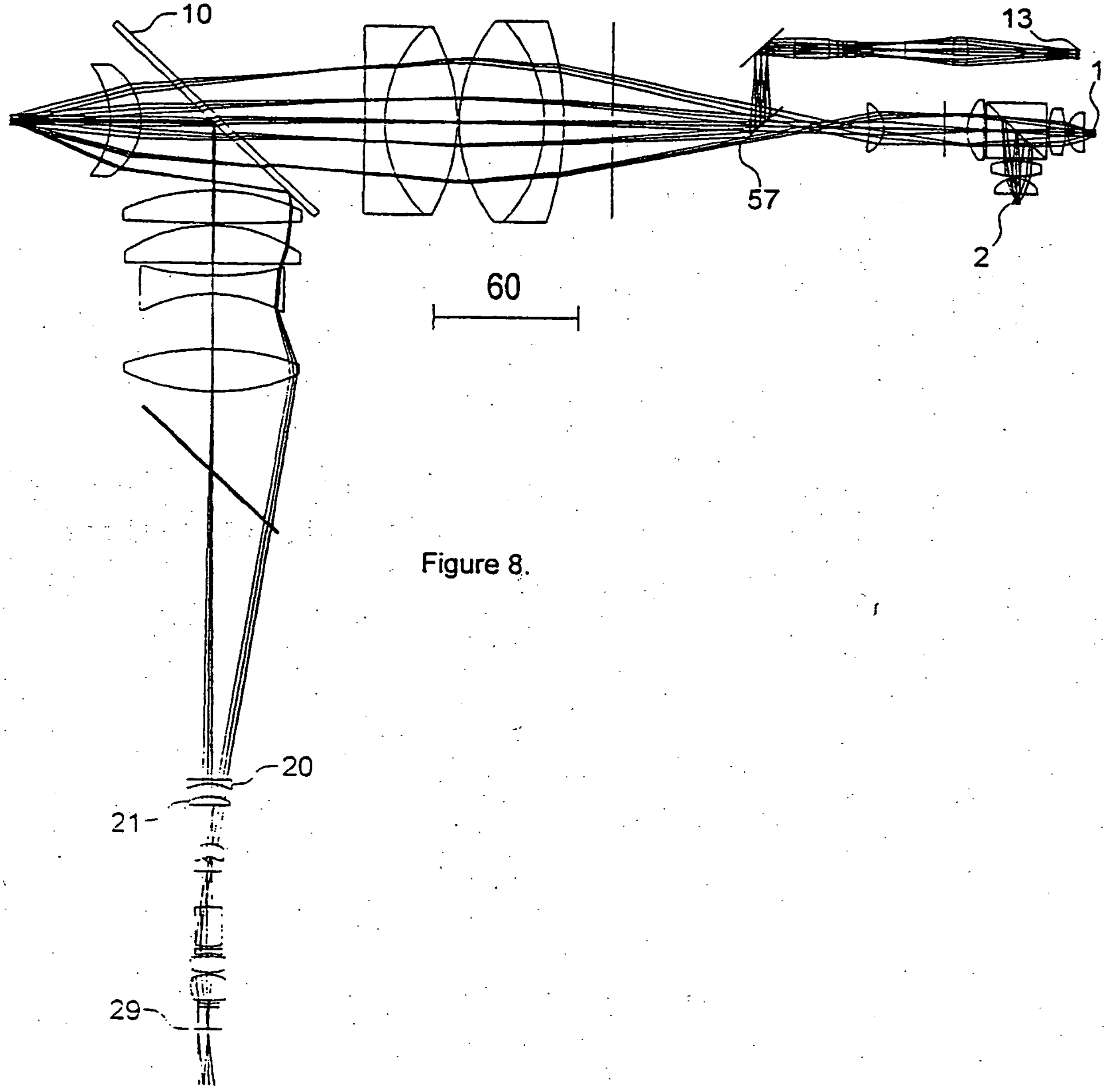


Figure 8.

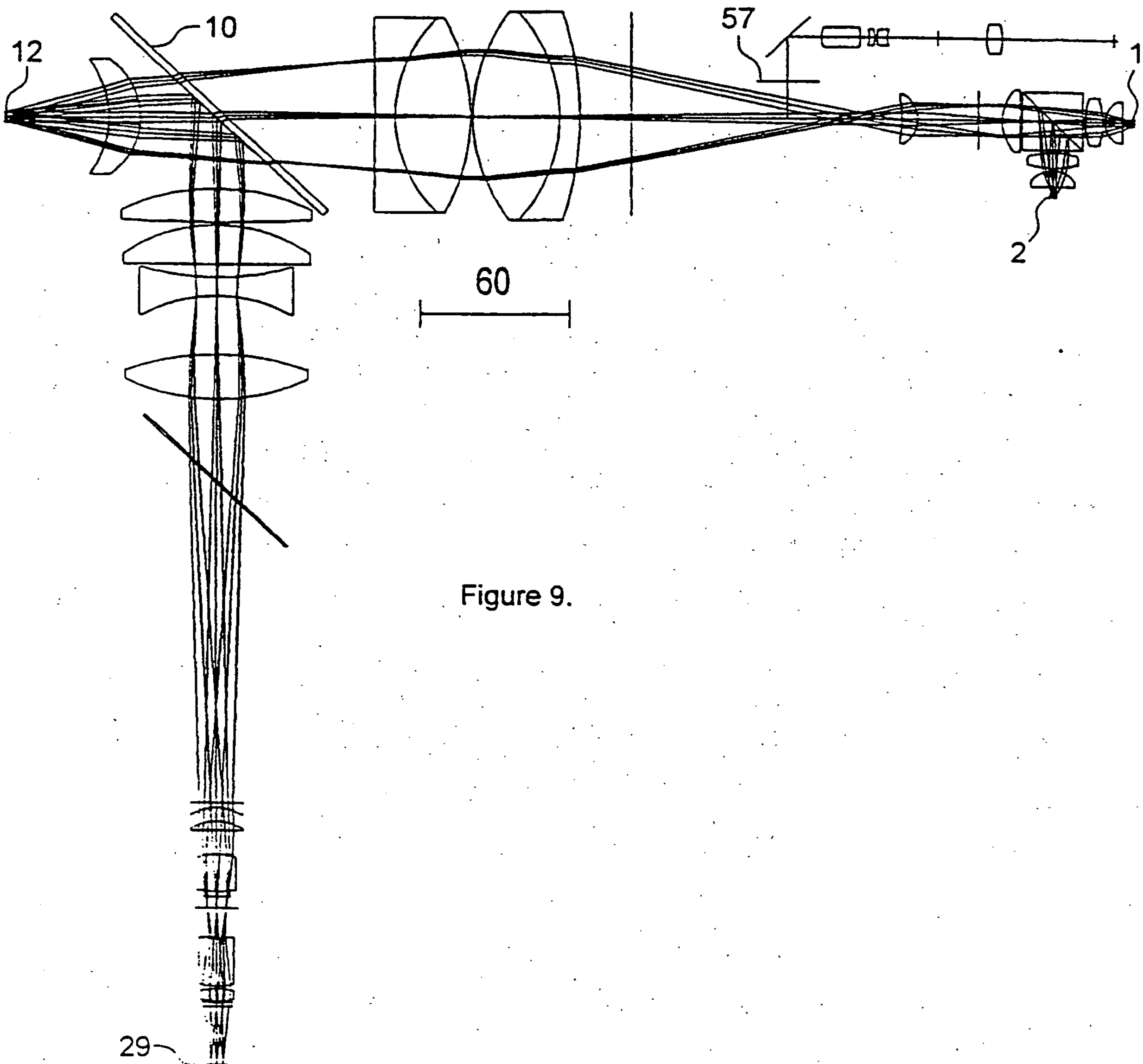


Figure 9.

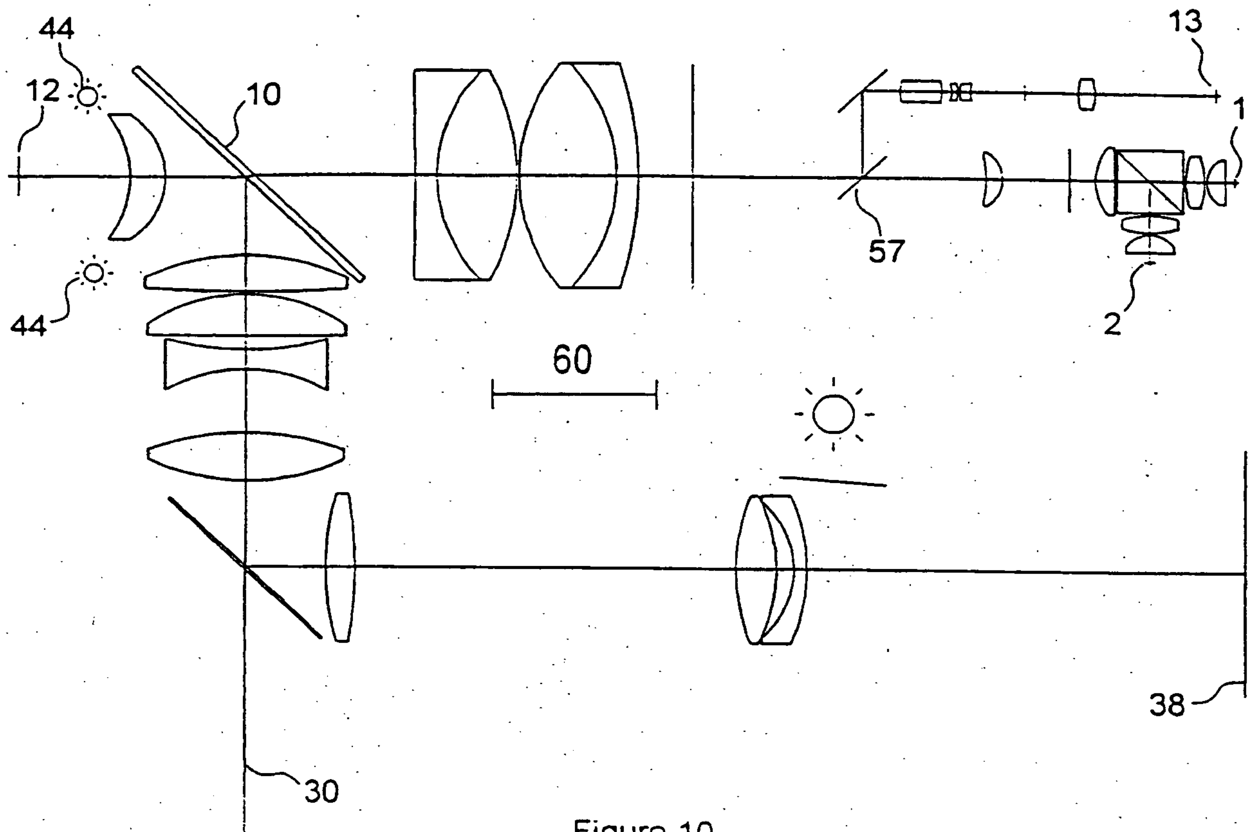
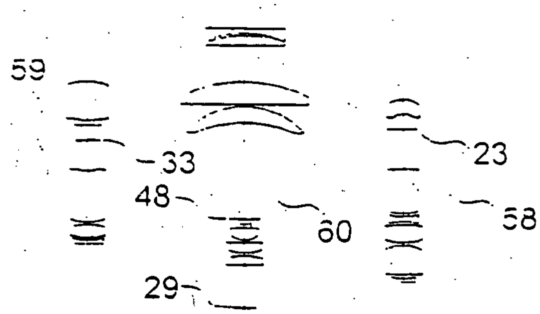


Figure 10.



INTERNATIONAL SEARCH REPORT

Inte. .ional Application No
PCT/GB 01/00620

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61B3/18 A61B3/12 A61B3/113 A61B3/103

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 1997, no. 01, 31 January 1997 (1997-01-31) & JP 08 224213 A (NIKON CORP), 3 September 1996 (1996-09-03) abstract; figures 1,5-9	1-13, 19-31
X	US 5 416 538 A (YAMADA KENJI) 16 May 1995 (1995-05-16) column 1, line 50 -column 3, line 56 column 4, line 21 -column 5, line 61 column 6, line 31-66; figures 1,3-5,7	1-11,13, 25,26, 28,30,31

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
8 May 2001	17/05/2001
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Casse, M

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International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 1997, no. 08, 29 August 1997 (1997-08-29) & JP 09 094225 A (CANON INC), 8 April 1997 (1997-04-08) abstract; figures 1,14,19-26	1-3,5, 8-13,15, 16,19-31
X	EP 0 284 248 A (KOWA CO) 28 September 1988 (1988-09-28) column 5, line 22-46; figures 2-4,8,13	1-3
A	column 9, line 25 -column 11, line 42	15,16
X	US 5 321 446 A (MASSIG JURGEN ET AL) 14 June 1994 (1994-06-14)	1-3
A	column 2, line 33 -column 4, line 2; figures 1A,2A column 4, line 25 -column 5, line 12 column 5, line 56 -column 7, line 64	13,14, 19-31
X	US 4 558 932 A (NUNOKAWA KAZUO) 17 December 1985 (1985-12-17) column 1, line 55 -column 2, line 22; figure 1 column 2, line 42 -column 4, line 13	1-4,6,7
X	WO 00 04820 A (BINNUN EMMANUEL ;TALIA TECHNOLOGY LTD (IL)) 3 February 2000 (2000-02-03) page 3, line 8 -page 8	1
A	figures 2,3	3,4,6,7, 11-13, 30,31
X	US 4 235 540 A (HANAMURA YOSHIHIKO ET AL) 25 November 1980 (1980-11-25) column 2, line 58 -column 3, line 39; figures 1,7	1-3
A	column 5, line 34-58	4-7,9

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 01/00620

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 08224213 A	03-09-1996	NONE	
US 5416538 A	16-05-1995	JP 6137841 A	20-05-1994
		DE 4336867 A	05-05-1994
JP 09094225 A	08-04-1997	NONE	
EP 0284248 A	28-09-1988	JP 63238843 A	04-10-1988
		DE 3886243 D	27-01-1994
		DE 3886243 T	05-05-1994
		US 5090416 A	25-02-1992
US 5321446 A	14-06-1994	DE 4205865 A	02-09-1993
		JP 5337086 A	21-12-1993
US 4558932 A	17-12-1985	JP 1676155 C	26-06-1992
		JP 2012572 B	22-03-1990
		JP 59049737 A	22-03-1984
WO 0004820 A	03-02-2000	AU 4927099 A	14-02-2000
US 4235540 A	25-11-1980	JP 1376541 C	08-05-1987
		JP 54147684 A	19-11-1979
		JP 61046131 B	13-10-1986
		JP 54147685 A	19-11-1979
		JP 1450521 C	11-07-1988
		JP 54147686 A	19-11-1979
		JP 61043055 B	25-09-1986